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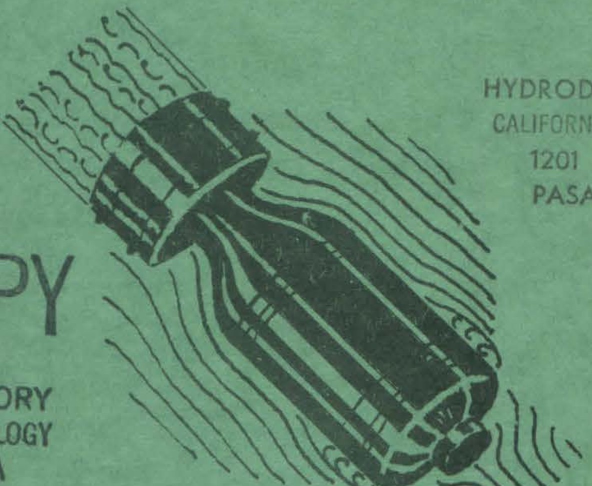
TESTS OF THE 5" HVAR PROJECTILE WITH FIN AND RING TAILS



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

SECTION Nº 6.1-sr 207-2241
LABORATORY Nº ND-37

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TESTS OF THE
5" HVAR PROJECTILE
WITH FIN AND RING TAILS

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Section No. 6.1-sr207-2241

Laboratory No. ND-37

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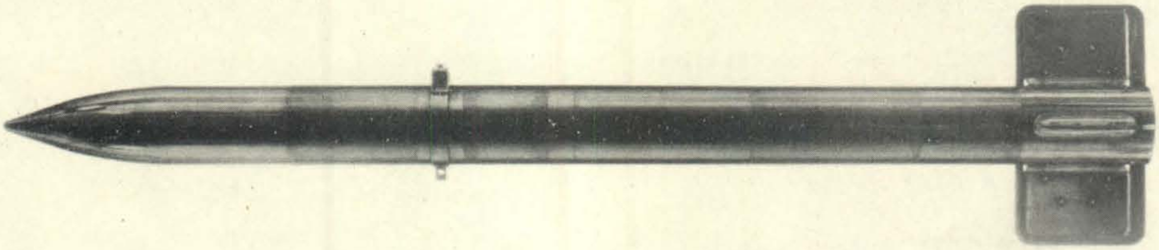


5" HVAR PROJECTILE WITH STANDARD FIN TAIL

TESTS OF THE
5" HVAR PROJECTILE
WITH FIN AND RING TAILS

GENERAL

This report covers tests of a 2-inch diameter model of the 5" HVAR Projectile, conducted at the Hydrodynamics Laboratory of the California Institute of Technology. This work was authorized by a letter dated January 31, 1944, from Dr. E. H. Colpitts, Chief of Section 6.1, Office of Scientific Research and Development.

The purpose of the tests was to determine the performance of the projectile with the standard 4-fin tail, and to investigate possible changes in the proportions of the fins in order to better the performance or make a more compact design. This report also includes an extensive investigation of the performance of various fin and ring tails applied to this projectile, as well as to similar projectiles of different lengths. It is hoped that the data contained herein may be of use in the design of a variety of bullet-shaped projectiles having either ring or fin tails.

The Water Tunnel tests apply only to the projectile moving at subsonic speeds, i.e., during the acceleration period.

The attached appendix gives definitions of the terms used throughout the text, as well as other pertinent data.

DESCRIPTION OF PROJECTILE

The frontispiece is a photograph of the model with the standard fin tail (laboratory designation No. 87), and Figure 1 is an outline drawing of the prototype. All fin tails were made similar to that shown in Figure 1. The following data pertain to this

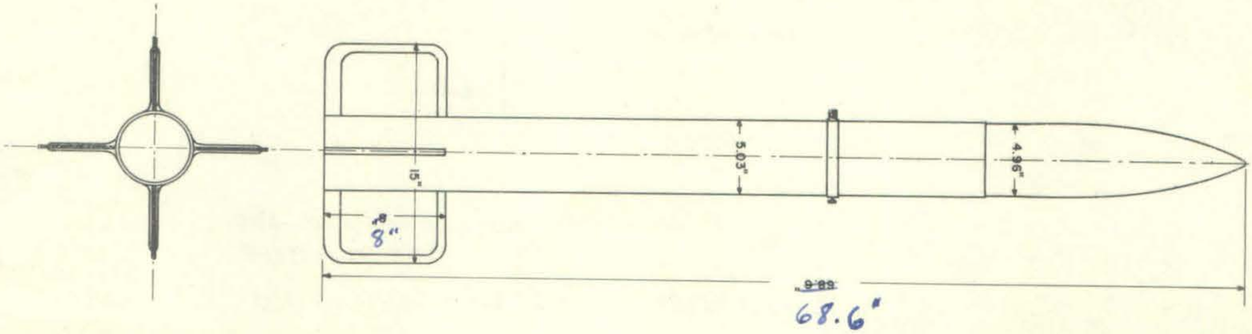
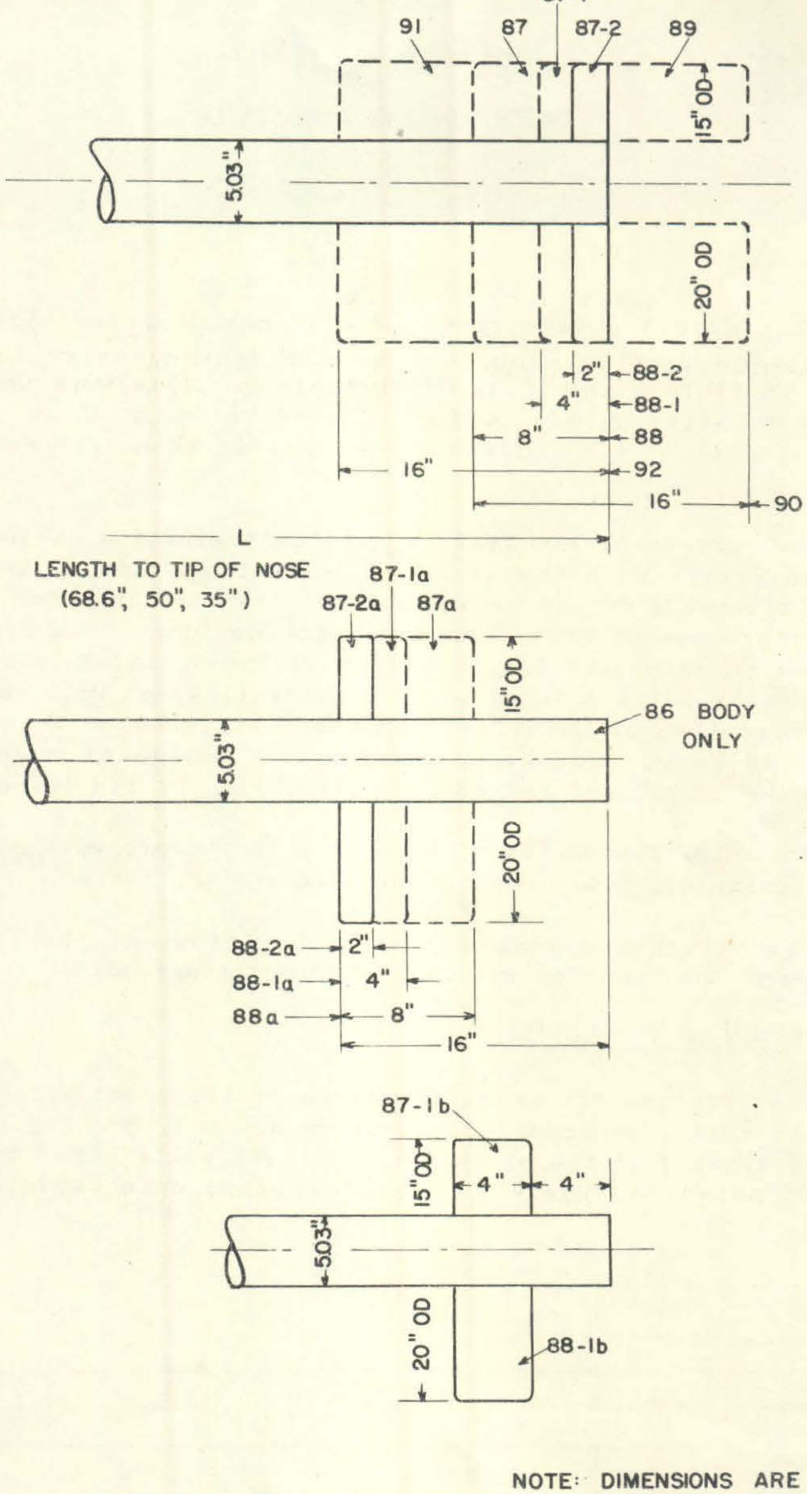


FIG. 1 – OUTLINE DRAWING OF 5" HVAR PROJECTILE



NOTE: DIMENSIONS ARE
FOR PROTOTYPE

FIG. 2 — DETAILS OF FIN TAILS TESTED

projectile:

Length overall	68.60 inches = 13.64 calibers
Maximum diameter	5.03 inches = 1 caliber
Outside diameter of fins	15 inches = approx. 3 cal.
Length of fins	8 inches = approx. 1.6 cal.
Loaded weight	136.5 pounds
Weight in flight	112.5 pounds
Radius of gyration	1.82 feet
Velocity	1375 feet per second
Nose to center of gravity	32 inches = 6.36 calibers

For tests made with other than the standard length of projectile the center-of-gravity distance was taken to be as follows:

Overall length = 10 calibers - Nose to C.G. = 4.64 calibers

Overall length = 7 calibers - Nose to C.G. = 3.3 calibers

TESTS OF FIN TAILS

In addition to theregular fin tail used with this projectile, a large number of fins of different sizes and locations on the body was tested. These tests have provided useful data for predicting the performance of new fin tail designs.

Figure 2 shows the various combinations tested. As will be discussed later, these combinations made possible the determination of the variation in the moment coefficient for the following arrangements: starting with a narrow fin at the aft end of the body and increasing the fin length forward to a maximum of 16 inches; starting with a narrow fin 16 inches forward of the aft end of the body and increasing the fin length aft to the end of the body; starting with a fin 8 inches from the aft end of the body and increasing the fin length until it extended 8 inches aft of the end of the body. All of these tests were made with fins 15 inches and 20 inches outside diameter.

FIN TAIL FORCE COEFFICIENTS

Figures 3 to 5 show the moment and cross force coefficients for the various fin tail combinations and projectile lengths. These curves give the basic data used for the comparison of the different fin tail designs. Their meaning is more significant when replotted to admit of more ready comparison, as the following discussion will show.

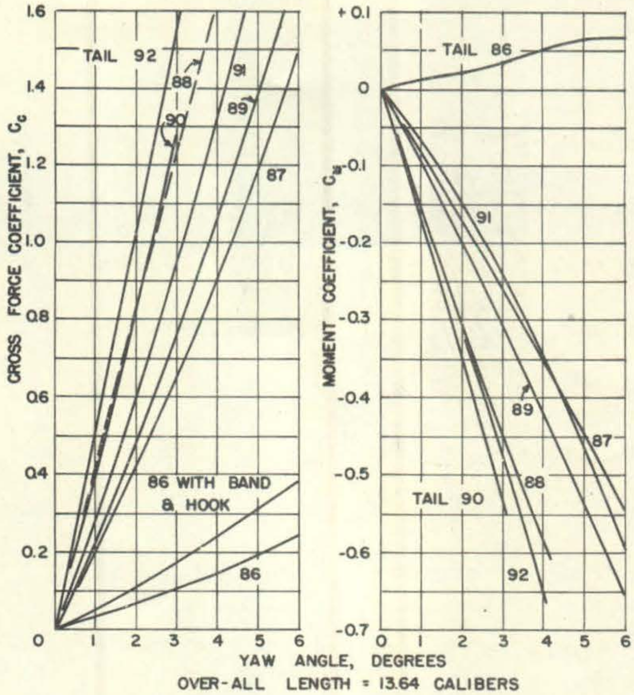


FIG. 3 — MOMENT AND CROSS FORCE COEFFICIENTS

TAILS NO. 86, 87, 88, 89, 90, 91, 92

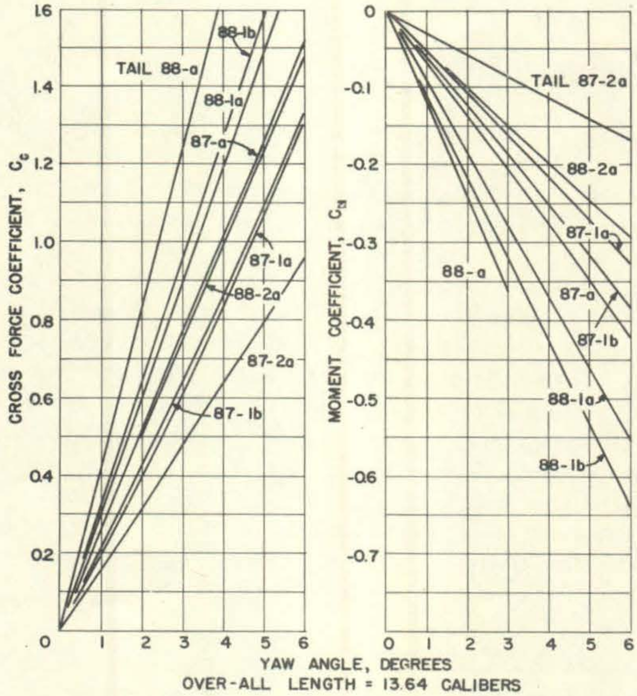


FIG. 4 — MOMENT AND CROSS FORCE COEFFICIENTS

TAILS NO. 87A, 87-1A, 87-2A, 88-1A, 88-2A, 87-1B, 88-1B

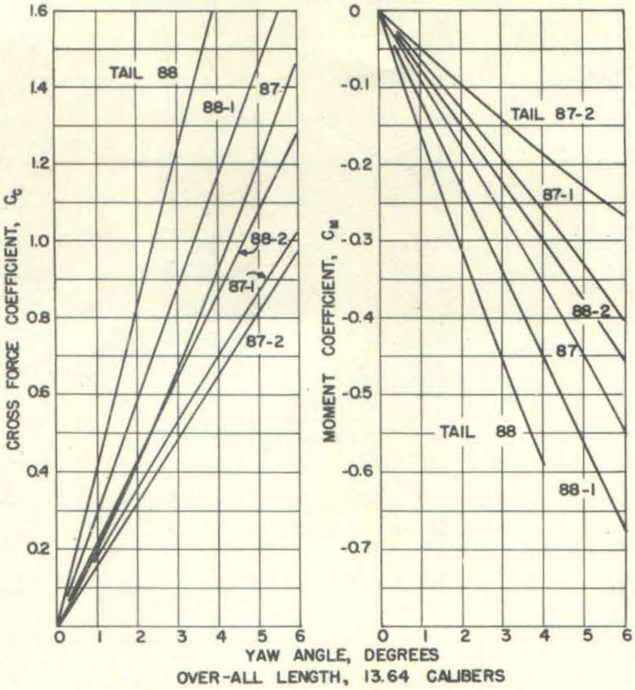


FIG. 5 – MOMENT AND CROSS FORCE COEFFICIENTS
TAILS NO. 87, 87-1, 87-2, 88, 88-1, 88-2

In Figure 6 the moment coefficient is plotted against the outside diameter of the fins for various fin lengths increasing from the aft end of the body. Figure 7 shows the same data which have been replotted to show the variation in moment coefficient as the fins increase in length. This shows clearly that there is little if any advantage in making the fin more than 1.5 calibers long, as no great change in moment coefficient results. It also shows that comparatively small changes in the outside diameter of the fins result in rather large increases in the moment coefficient.

All of these curves have been plotted for a 3° yaw angle. As the moment and cross force coefficients are practically straight lines for all yaw angles up to 3°, the coefficients for other yaws can be obtained by direct proportion.

In Figures 8 and 9 similar curves are plotted for the series of tails starting 16 inches forward of the end of the body and increasing in length aft. Figure 9 shows that there is a more rapid increase in moment coefficient with increasing length of fin than in the case shown in Figure 7, but it is still evident that the most effective way to increase the moment is by increasing the outside diameter of the fins.

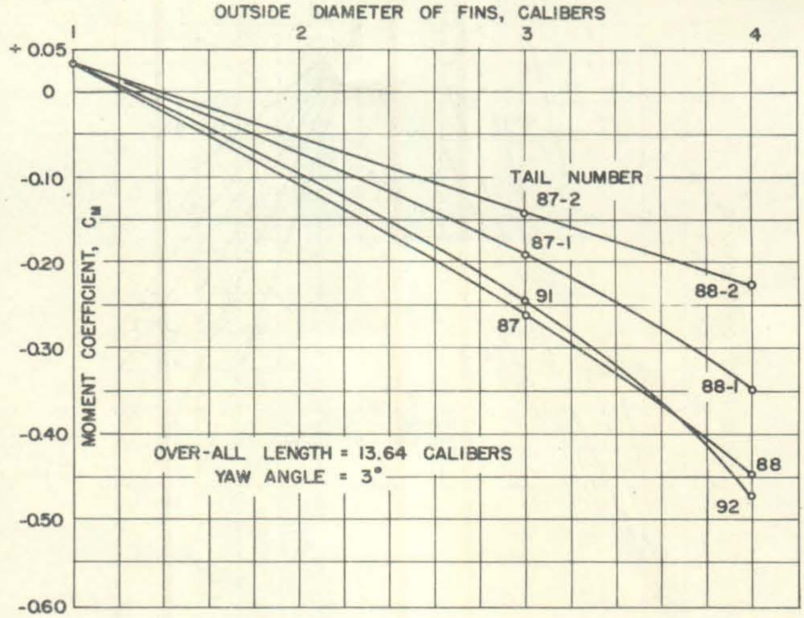


FIG. 6 - MOMENT COEFFICIENT VS. FIN DIAMETER

FIN LENGTH INCREASING FORWARD

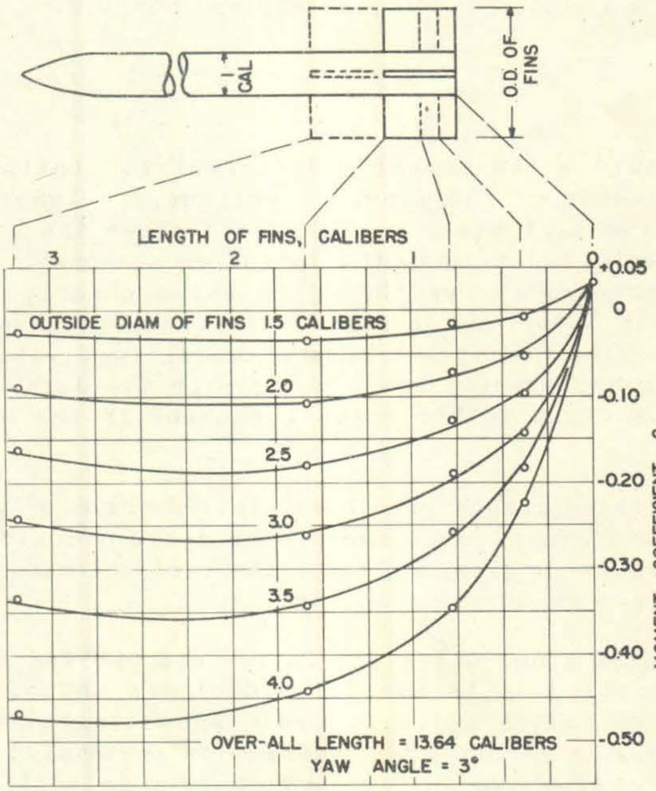


FIG. 7 - MOMENT COEFFICIENT VS. FIN LENGTH AND DIAMETER

FIN LENGTH INCREASING FORWARD

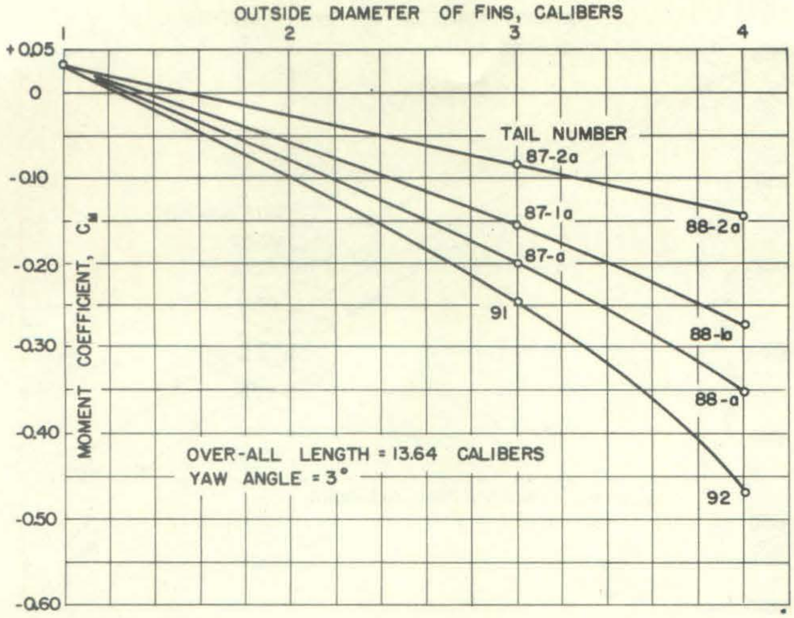


FIG. 8 — MOMENT COEFFICIENT VS. FIN DIAMETER

FIN LENGTH INCREASING AFT

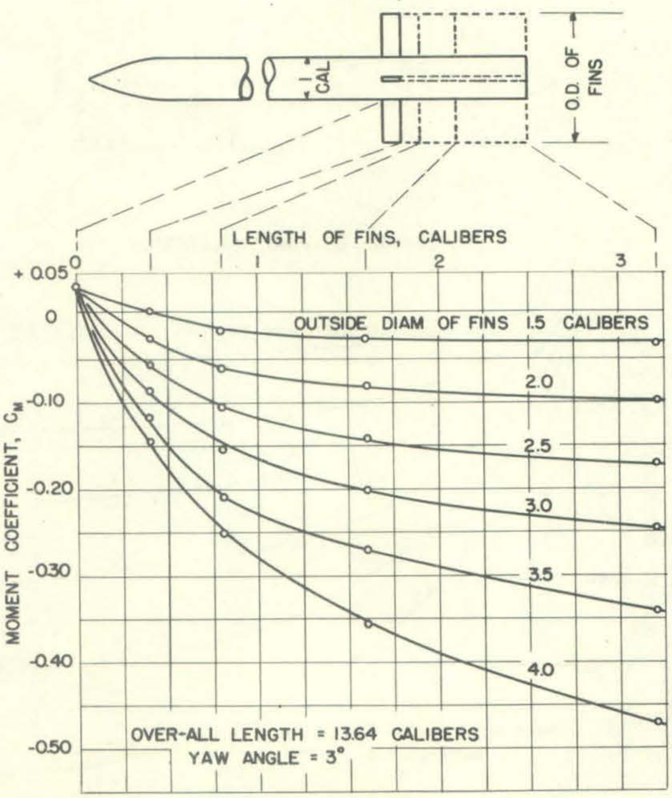


FIG. 9 — MOMENT COEFFICIENT VS. FIN LENGTH AND DIAMETER

FIN LENGTH INCREASING AFT

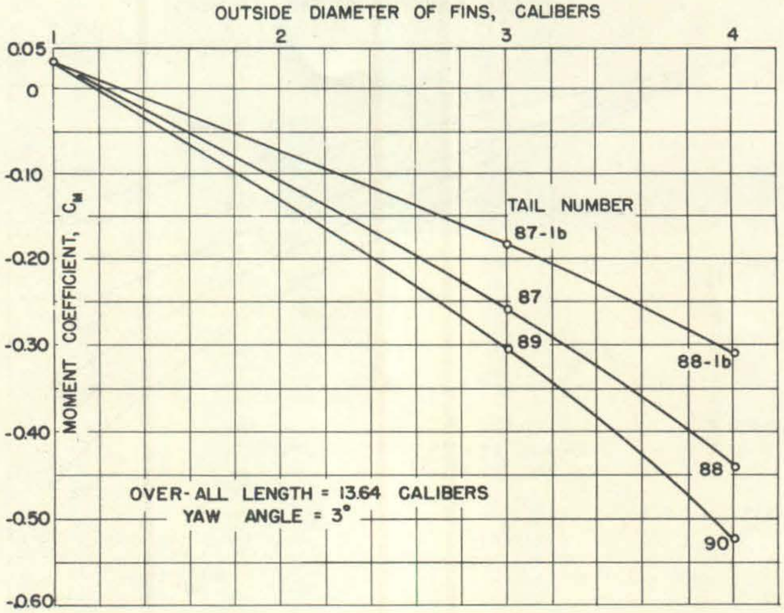


FIG. 10 — MOMENT COEFFICIENT VS. FIN DIAMETER
FINS EXTENDING AFT OF BODY

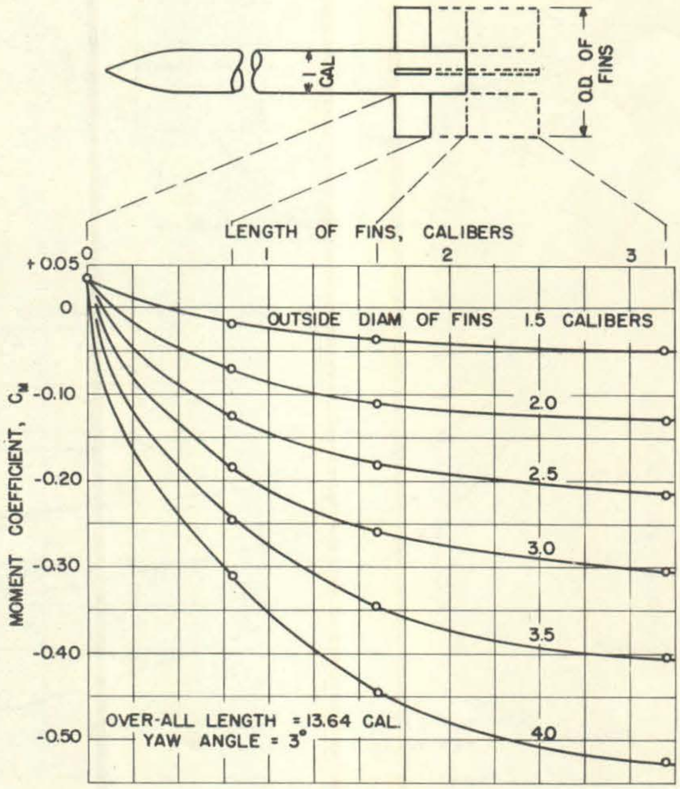


FIG. 11 — MOMENT COEFFICIENT VS. FIN LENGTH AND DIAMETER
FINS EXTENDING AFT OF BODY

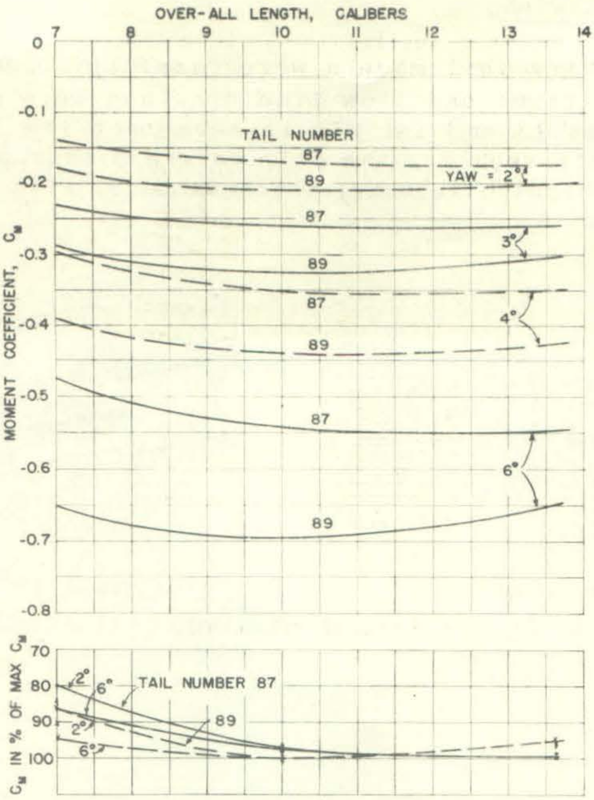


FIG. 12 - MOMENT COEFFICIENTS VS. BODY LENGTH
TAILS NO. 87 AND NO. 89

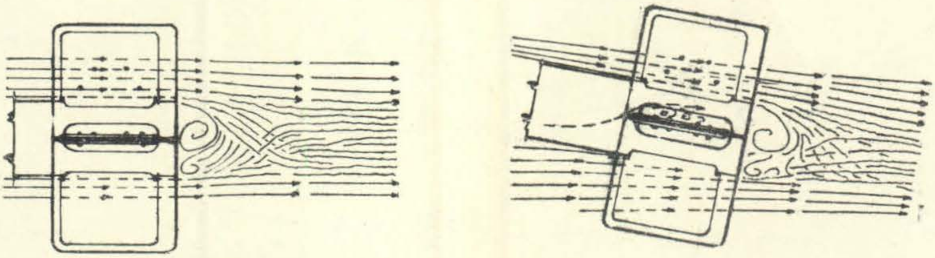
Figures 10 and 11 show the effect of starting with the fin 8 inches forward of the end of the body and extending to a distance 8 inches aft of the body end.

The tail extended 8 inches aft of the body results in a greater moment coefficient than was obtained with the other arrangements due to the increase in the distance from C.G. of the projectile to the center of pressure of the fins.

Tests were made on two tails (No. 87 and No. 89) fitted to bodies having overall lengths of 13.64, 10, and 7 calibers. The moment coefficients for these combinations are plotted in Figure 12. For small yaw angles the moment coefficient is quite constant and is not greatly affected by the length of the projectile. This is not the case for yaws over about 2°. At the bottom of Figure 12 is shown the variation in moment coefficient as a percentage of the maximum value. It is interesting to note that this ratio is the same for all yaw angles up to 6° for lengths between 10 and 14 calibers.

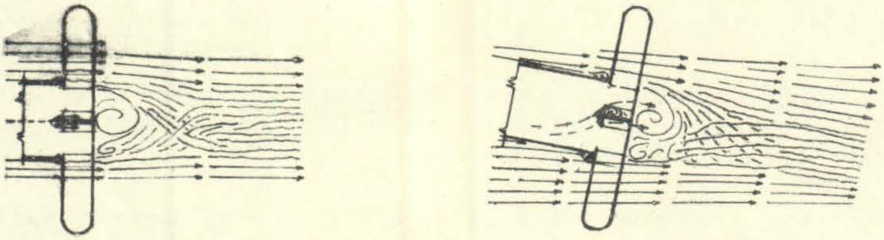
FLOW LINE DRAWINGS

Two of the fin-tail models were carefully examined in the Polarized Light Flume and flow line drawings were made. These appear as Figures 13 and 14. It is seen that the flow through the vanes is quite regular, the only severe disturbance being in the wake of the blunt afterbody, which is usual with such shapes.



YAW = 0° YAW = 10°

FIG. 13 - FLOW LINE DRAWING, TAIL NO. 87

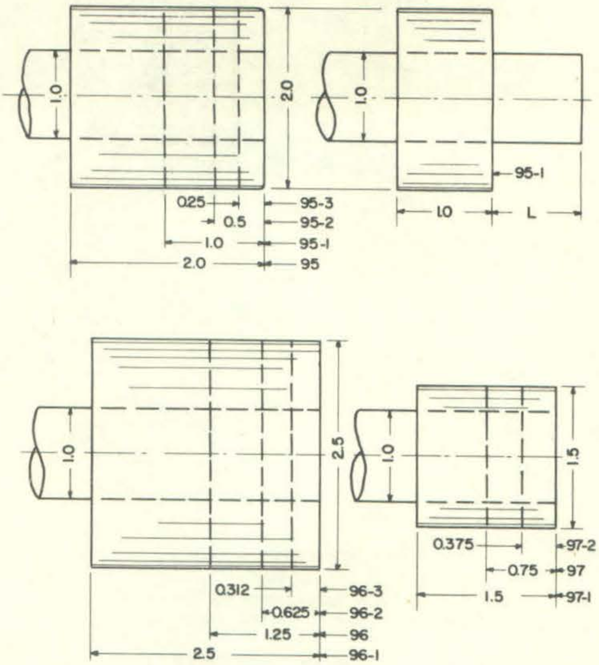


YAW = 0° YAW = 10°

FIG. 14 - FLOW LINE DRAWING, TAIL NO. 87-2

TESTS OF RING TAILS

Many tests were made with different sizes of ring tails, as it was thought this type of tail might prove superior to the fin tail normally used on this projectile.



ALL RINGS HAVE 4 FINS
RINGS AND FINS ARE OF 0.125 CALIBER THICKNESS
ALL DIMENSIONS ARE IN CALIBERS

FIG. 15 — RING TAIL DETAILS

Figure 15 shows the proportions of the various ring tails that were tested. These covered a wide variety of sizes and proportions, varying from 1.5 calibers to 2.5 calibers in diameter, and from 0.25 to 2.5 calibers in length. All of the ring tails had four radial fins the same length as the ring, and the ring and fins were made of metal 0.0125 calibers in thickness with no streamlining of the leading edges.

RING TAIL FORCE COEFFICIENTS

Figure 16 gives the cross force and moment coefficients for the various ring tails. It is seen that both the cross force and the moment coefficients vary in practically a straight-line relationship with the yaw angle.

Figure 17 shows the effect of moving a ring tail, 2 calibers in diameter and 1 caliber long, forward from its normal position at the end of the afterbody. As would be expected, this change in

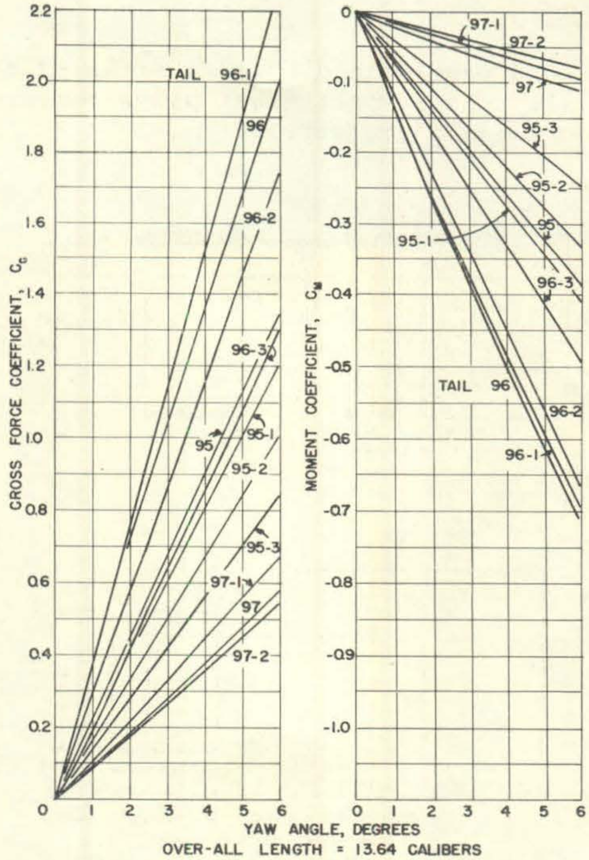


FIG. 16 — CROSS FORCE AND MOMENT COEFFICIENTS WITH RING TAILS
OVERALL LENGTH OF PROJECTILE — 13.64 CALIBERS

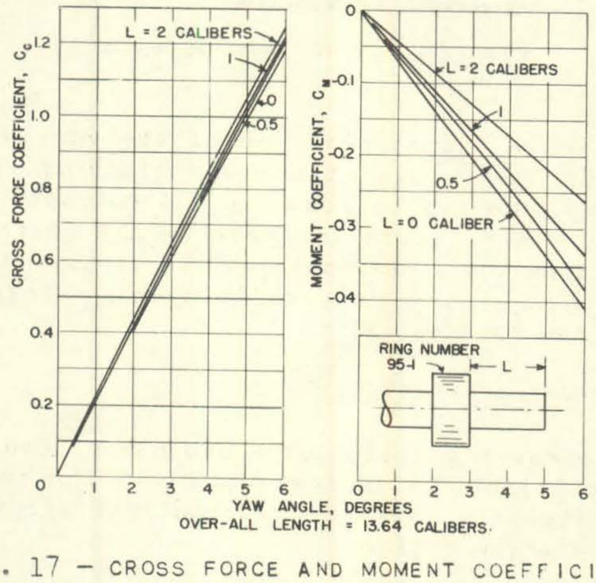


FIG. 17 — CROSS FORCE AND MOMENT COEFFICIENTS
RING TAIL FORWARD OF END OF BODY

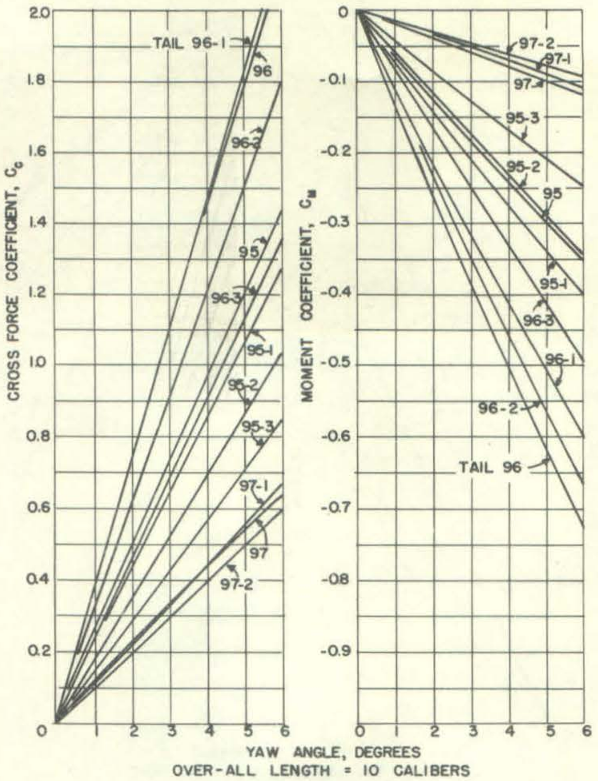


FIG. 18 – CROSS FORCE AND MOMENT COEFFICIENTS WITH RING TAILS
OVERALL LENGTH OF PROJECTILE – 10 CALIBERS

in position results in a decided decrease in the moment coefficient as the tail moves forward. The cross force coefficient is affected very little by this change in the position of the ring.

Figure 18 shows the force coefficients for the ring tails with the overall projectile length reduced to 10 calibers, and Figure 19 gives the same information for a length of 7 calibers.

EFFECT OF RING LENGTH

Figure 20 shows the effect on the moment coefficient of changing the length of the ring. These curves are for ring diameters of 1.5, 2.0, and 2.5 calibers, and yaw angles up to 6°.

It is of much interest to note the very rapid increase in moment coefficient with small changes in ring length. This increase in moment coefficient continues until the length of ring is practically one-half the ring diameter when a maximum value of the moment coefficient is generally reached. Any increase in length of ring beyond this proportion is of no value in increasing the stabilizing moment.

The data in Figure 20 are plotted in different form in Figure 21. Here the moment coefficient is expressed as a percentage of

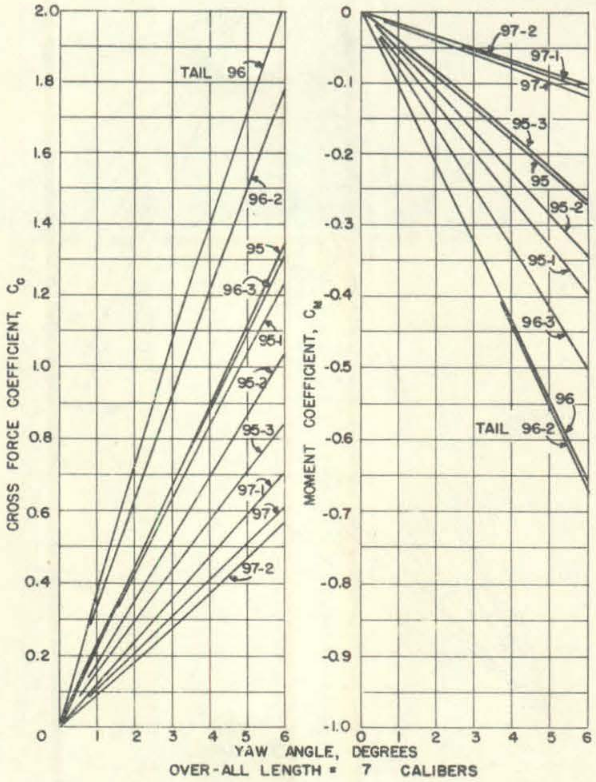


FIG. 19 – CROSS FORCE AND MOMENT COEFFICIENTS WITH RING TAILS
OVERALL LENGTH OF PROJECTILE – 7 CALIBERS

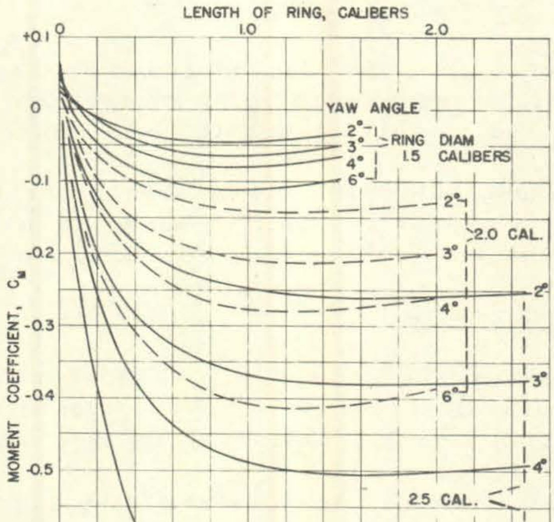


FIG. 20 – MOMENT COEFFICIENT VS. LENGTH
AND DIAMETER OF RING

the maximum value. It is very significant to observe how closely one curve will represent the data for all tails up to the maximum value of the moment. Beyond this maximum value there is a wide divergence, but this is not of importance as this region is for lengths of rings that would not be economical to use.

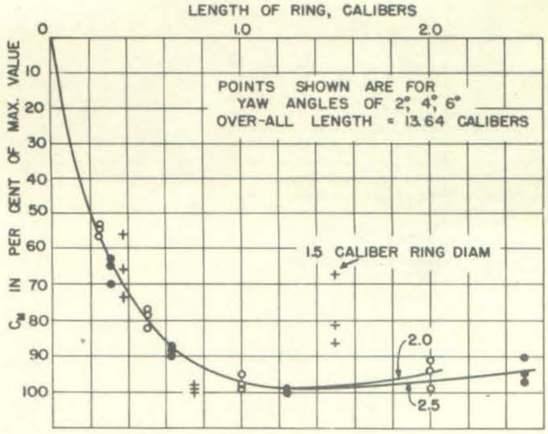


FIG. 21 — MOMENT COEFFICIENT VS. LENGTH AND DIAMETER OF RING (MOMENT AS A PER CENT OF THE MAXIMUM VALUE)

EFFECT OF DIAMETER ON RING

In Figure 22 is shown the effect, on the moment coefficient, of changing the diameter of the ring, all rings having a length of one-half the ring diameter, which was found to be about the optimum value. The stabilizing moment seems to increase about as the square of the ring diameter. a ring having a diameter of 1.25 calibers will produce a stabilizing moment that just neutralizes the destabilizing moment of the body without a tail, or, in other words, with a ring diameter of

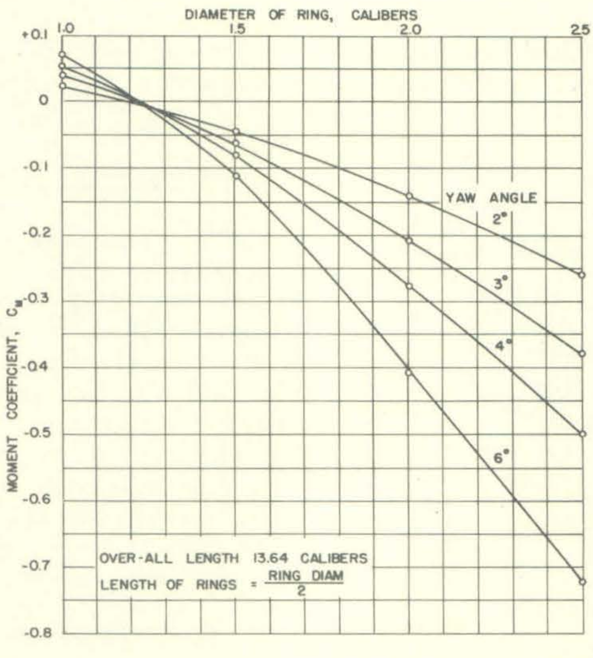


FIG. 22 — MOMENT COEFFICIENT VS. DIAMETER OF RING

RING LENGTH EQUALS ONE-HALF RING DIAMETER

1.25 calibers, the moment coefficient becomes zero. This condition will be affected by the location of the point about which the moments are calculated.

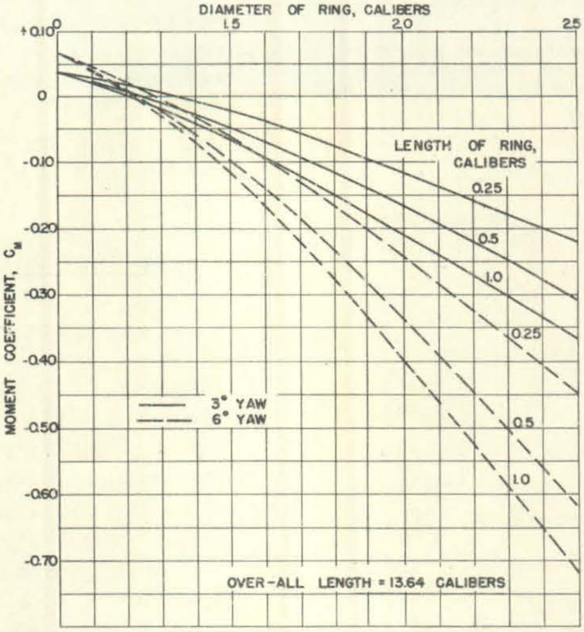


FIG. 23 — MOMENT COEFFICIENT VS. DIAMETER OF RING
RING LENGTH OF 0.25, 0.50, 1.0 CALIBER

Figure 23 shows the variation of the moment coefficient with rings of different lengths as well as different diameters. The data are plotted for yaws of 3° and 6°.

EFFECT OF RING POSITION

A series of tests was made with a ring 2 calibers in diameter and 1 caliber in length. This ring was tested in four positions, that is, at the end of the body and also moved forward 1/2, 1, and 2 calibers. The effects of these changes in position are shown in Figure 24 where it is seen that the moment coefficient decreases in a linear relation with the distance of the ring from the end of the body. Moving the ring 1 caliber from the end of the body reduces the moment coefficient approximately 20 per cent.

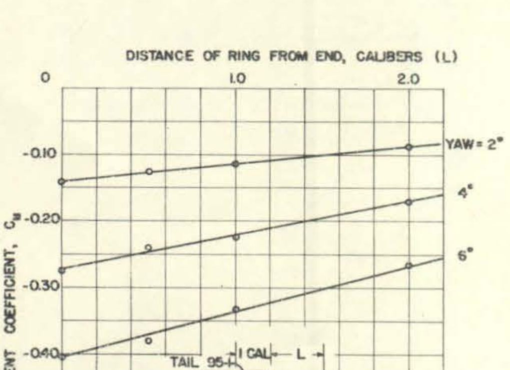


FIG. 24 — MOMENT COEFFICIENT VS. POSITION OF RING

EFFECT OF PROJECTILE LENGTH

Certain of the ring tails were tested with overall lengths of projectile of 13.64, 10, and 7 calibers. These tests were made in order to obtain data that would be applicable to other projectiles of less length than the 5" HVAR.

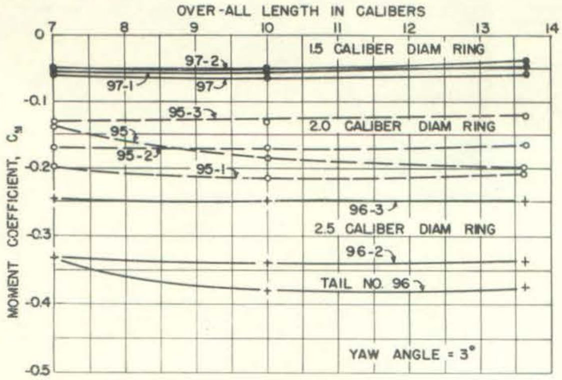


FIG. 25 – MOMENT COEFFICIENT VS. BODY LENGTH – RING TAILS

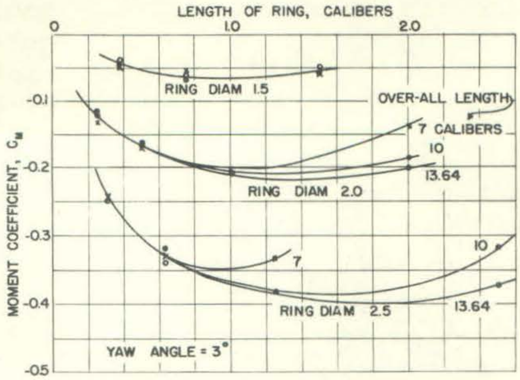


FIG. 26 – MOMENT COEFFICIENT VS. LENGTH OF RING AND BODY LENGTH

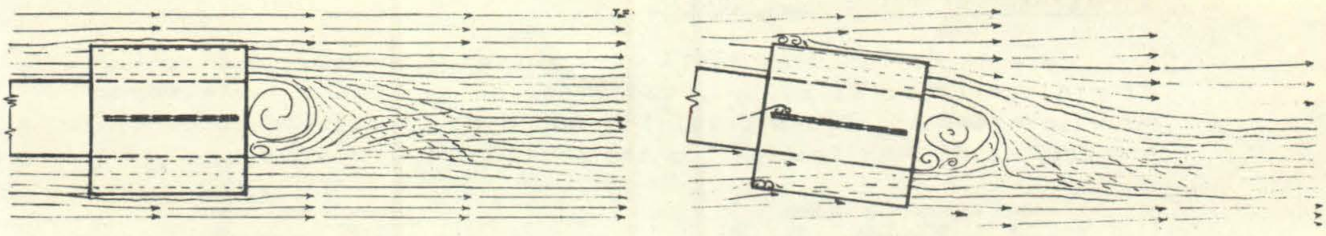
Figure 25 shows the variation in the moment coefficient with the length of projectile for several ring tails. The remarkable thing about this series of curves is the almost constant value of moment coefficient, for a given tail, throughout the range of projectile lengths from 7 to 14 calibers.

In Figure 26 the variation in moment coefficient with length of ring is shown for various projectile lengths. The moment coefficient is quite constant for all lengths of projectile, for a given diameter of ring, up to a ring length of about 1 caliber. Beyond this point there is considerable divergence but, as before noted, this is not of importance since these longer rings are not effective in increasing the stabilizing moment.

FLOW LINE DRAWINGS

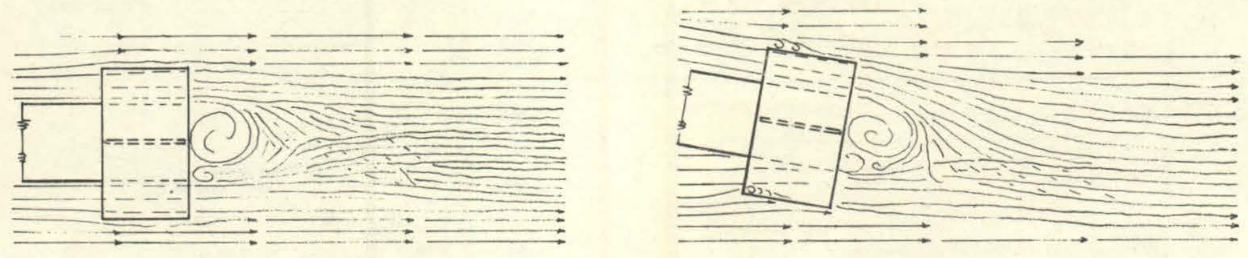
Several of the ring tails were examined in the Polarized Light Flume and drawings of the flow lines around the model were made. Figure 27 gives the flow line drawings for three tails having a diameter of 2 calibers and lengths of 2, 1, and 0.25 calibers, also, for one tail 1.5 calibers in diameter and 0.75 calibers in length. All drawings show a fairly uniform flow through the ring and the typical vortex in the wake of the blunt afterbody. It was observed that there was a slight vortex after the leading edges of all the rings with the exception of the smallest (1.5 calibers in diameter).

Figure 28 shows the flow lines with the 2-caliber diameter x 1-caliber ling ring moved 2 calibers forward from the end of the body.



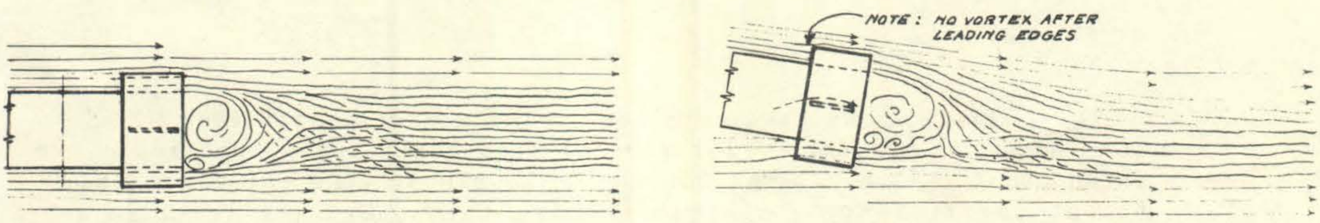
YAW = 0°   YAW = 10°

RING TAIL NO. 95



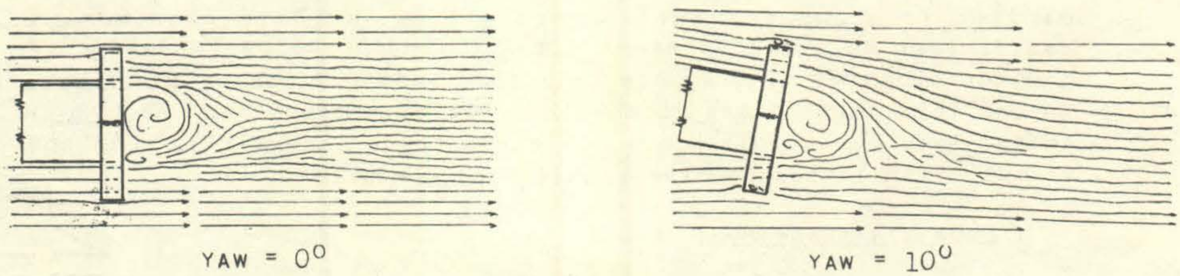
YAW = 0°   YAW = 10°

RING TAIL NO. 95-1



YAW = 0°   YAW = 10°

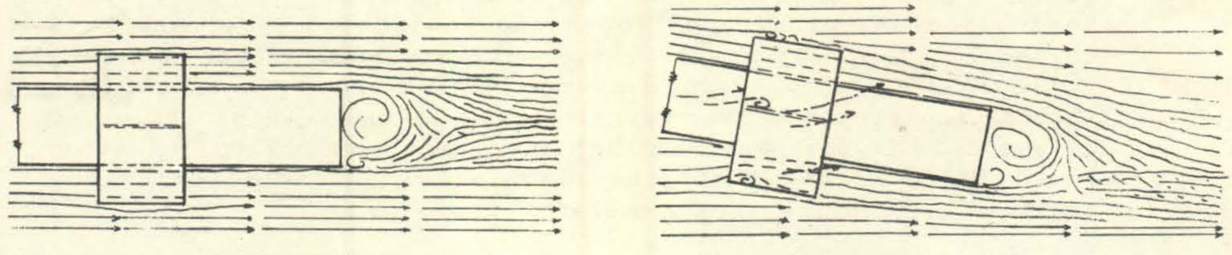
RING TAIL NO. 95-3



YAW = 0°   YAW = 10°

RING TAIL NO. 97

FIG. 27 – FLOW LINE DRAWINGS



YAW = 0°   YAW = 10°

FIG. 28 – FLOW LINE DRAWINGS, RING TAIL 2 CALIBERS FROM END OF BODY

RING AND FIN TAILS COMPARED

The ring tail appears to have decided advantages over the fin tail from the standpoint of physical dimensions. On the other hand, the fin tail permits the rocket to be fired from ways on which the rocket body can rest; also, any hooks or eyes used for suspending the rocket can be close to the body, which could not be possible if a ring tail were used.

A few outline drawings of ring and fin tails will easily illustrate the excessive size of fins required to produce the same stabilizing moment. In Figure 29 are shown three tails with outside diameters of 1.5, 2.0, and 2.5 calibers. For each diameter the fin and ring tails will produce the same moment. In this instance the fins could be half as long without appreciably altering the moment, as has been pointed out before.

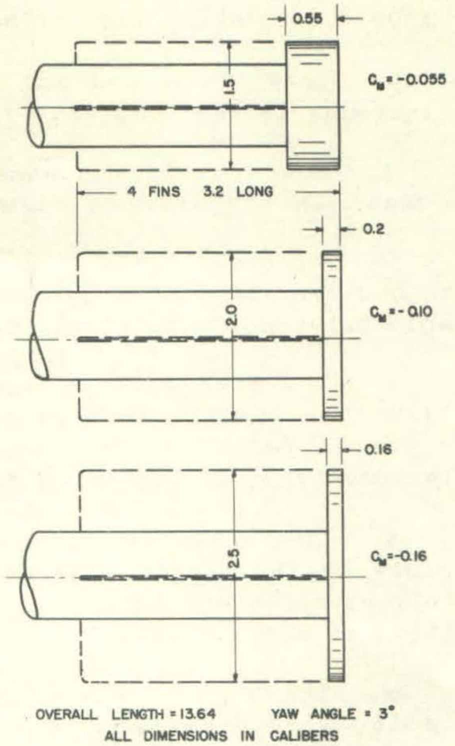


FIG. 29 — RELATIVE SIZES OF EQUIVALENT FIN AND RING TAILS

In Figure 30 are shown the proportions of six tails all providing the same moment coefficient. These outlines illustrate the great increase in length required for both the rings and fins to offset a comparatively small decrease in outside diameter. These outlines also indicate the greater space required for a fin tail.

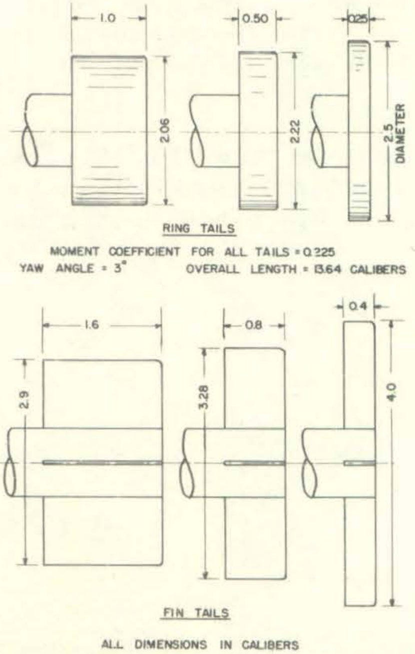


FIG. 30 — RING AND FIN TAILS HAVING THE SAME MOMENT COEFFICIENT

CONCLUSIONS

As a result of this investigation, the following conclusions in regard to stablilzing surfaces seem to be justified:

1. Very little, if any, increase in stability results from an increase in the length of fins over 1.5 calibers.

2. The stabilizing moment increases very rapidly with an increase in the outside diameter either of fin or ring tails.

3. The moment coefficient is quite constant for a projectile with a given fin tail at yaw angles less than 4° and with over-all length between 10 and 14 calibers.

4. The ring tail is far more efficient in producing stability than the fin type of tail when physical dimensions alone are considered. The ring type of tail will cause interference with some types of launching mechanisms.

5. The moment coefficient, with a ring tail, increases rapidly as the length of ring increases up to a length approximately equal to one-half the ring diameter, and beyond this length, little, if any, increase in stability results.

6. There is a very rapid increase in stability with increasing ring diameter. A ring diameter of 1.25 calibers just about neutralizes the destabilizing moment of the body without a tail, with moments calculated about the C.G. location in this particular case.

7. Moving the ring forward from the end of the body reduces the stability. A reduction of 20 per cent in the moment coefficient will result if the ring is placed one caliber from the body end.

8. The moment coefficient for a given ring tail remains practically constant for all over-all lengths of projectile between 7 and 14 calibers. Only two of the ten rings tested departed from this general rule.

APPENDIX

DEFINITIONS

YAW ANGLE, ψ

The angle, in a horizontal plane, which the axis of the projectile makes with the direction of motion. Looking down on the projectile, yaw angles in a clockwise direction are positive (+) and in a counterclockwise direction, negative (−).

PITCH ANGLE, α

The angle, in a vertical plane, which the axis of the projectile makes with the direction of motion. Pitch angles are positive (+) when the nose is up and negative (−) when the nose is down.

LIFT, L

The force, in pounds, exerted on the projectile normal to the direction of motion and in a vertical plane. The lift is positive (+) when acting upward and negative (−) when acting downward.

CROSS FORCE, C

The force, in pounds, exerted on the projectile normal to the direction of motion and in a horizontal plane. The cross force is positive when acting in the same direction as the displacement of the projectile nose for a positive yaw angle, i.e., to an observer facing in the direction of travel, a positive cross force acts to the right.

DRAG, D

The force, in pounds, exerted on the projectile parallel with the direction of motion. The drag is positive when acting in a direction opposite to the direction of motion.

MOMENT, M

The torque, in foot pounds, tending to rotate the projectile about a transverse axis. Yawing moments tending to rotate the projectile in a clockwise direction (when looking down on the projectile) are positive (+), and those tending to cause counterclockwise rotation are negative (−). Pitching moments tending to rotate the projectile in a clockwise direction (when looking at the projectile from the port side) are positive (+), and those tending to cause counterclockwise rotation are negative (−).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle or pitch angle, and a stabilizing effect when the moment and yaw or pitch angle have opposite signs

NORMAL COMPONENT, N

The sum of the components of the drag and cross force (or lift) acting normal to the axis of the projectile. The value of the normal component is given by the following:

$$N = D \sin \psi + C \cos \psi \qquad (1)$$

or

$$N = D \sin \alpha + L \cos \alpha \qquad (1a)$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

L = Lift force in lbs

ψ = Yaw angle in degrees

α = Pitch angle in degrees

CENTER OF PRESSURE, CP

The point in the axis of the projectile at which the resultant of all forces acting on the projectile is applied.

CENTER-OF-PRESSURE ECCENTRICITY, e

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (l) of the projectile. The center-of-pressure eccentricity is derived as follows:

$$e = (l_{cp} - l_{cg}) \frac{1}{l} = \frac{1}{l} \frac{M_{cg}}{N} \qquad (2)$$

in which

e = Center-of-pressure eccentricity

l = Length of projectile in feet

l_{cg} = Distance from nose of projectile to CG in feet

l_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The force and moment coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \quad (3)$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D} \quad (4)$$

Lift coefficient, $$C_L = \frac{L}{\rho \frac{V^2}{2} A_D} \quad (5)$$

Moment coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D l} \quad (6)$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

L = Measured lift force in lbs

ρ = Density of the fluid in slugs/cu ft = w/g

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D = Area in sq ft at the maximum cross section of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = Moment, in foot-pounds, measured about any particular point on the geometric axis of the projectile

l = Overall length of the projectile in feet

RUDDER EFFECT

The total increase or decrease in moment coefficient, at a given yaw or pitch angle, resulting from a given rudder setting. This increase or decrease in moment coefficient is measured from the moment coefficient curve for neutral rudder setting.

REYNOLDS NUMBER

In comparing hydraulic systems involving only friction and inertia forces, a factor called Reynolds number is of great utility. This is defined as follows:

$$R = \frac{lV}{\nu} = \frac{lV\rho}{\mu} \tag{7}$$

in which

R = Reynolds number

l = Overall length of projectile, feet

V = Velocity of projectile, feet per sec

ν = Kinematic viscosity of the fluid, sq ft per sec = μ/ρ

ρ = Mass density of the fluid in slugs per cu ft

μ = Absolute viscosity in pound-seconds per sq ft

Two geometrically similar systems are also dynamically similar when they have the same value of Reynolds number. For the same fluid in both cases, a model with small linear dimensions must be used with correspondingly large velocities. It is also possible to compare two cases with widely differing fluids provided l and V are properly chosen to give the same value of R.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, the cavitation parameter has been found very useful. This is defined as follows:

$$K = \frac{p_L - p_B}{\rho \frac{V^2}{2}} \tag{8}$$

in which

K = Cavitation parameter

p_L = Absolute pressure in the undisturbed liquid, lbs/sq ft

p_B = Vapor pressure corresponding to the water temperature, lbs/sq ft

V = Velocity of the projectile, ft/sec

ρ = mass density of the fluid in slugs per cu ft = w/g

w = weight of the fluid in lbs per cu ft

g = acceleration of gravity

Note that any homogeneous set of units can be used in the computation of this parameter. Thus, it is often convenient to express this parameter in terms of the head, i.e.,

$$K = \frac{h_L - h_B}{\frac{V^2}{2g}} \tag{9}$$

where

h_L = Submergence plus the barometric head, ft of water

h_B = Pressure in the bubble, ft of water

It will be seen that the numerator of both expressions is simply the net pressure acting to collapse the cavity or bubble. The denominator is the velocity pressure. Since the entire variation in pressure around the moving body is a result of the velocity, it may be considered that the velocity head is a measure of the pressure available to open up a cavitation void. From this point of view, the cavitation parameter is simply the ratio of the pressure available to collapse the bubble to the pressure available to open it. If the K for incipient cavitation is considered, it can be interpreted to mean the maximum reduction in pressure on the surface of the body measured in terms of the velocity head. Thus, if a body starts to cavitate at the cavitation parameter of one, it means that the lowest pressure at any point on the body is one velocity head below that of the undisturbed fluid.

The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter. If p_B is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, the behavior of the bubble will be the same whether the bubble is due to cavitation, the injection of exhaust gas, or the entrainment of air at the time of launching.

The cavitation parameter for incipient cavitation has the symbol K_i.

The following chart gives values of the cavitation parameter as a function of velocity and submergence in sea water.

GENERAL DISCUSSION OF STATIC STABILITY

Water tunnel tests are made under steady flow conditions, consequently the results only indicate the tendency of the steady state hydrodynamic couples and forces to cause the projectile to return to or move away from its equilibrium position after a disturbance. Dynamic couples and forces including either positive or negative damping are not obtained. If the hydrodynamic moments are restoring the projectile, then it is said to be statically stable, if nonrestoring, statically unstable. In the discussion of static stability the actual motion following a perturbation is not considered at all. In fact, the projectile may oscillate continuously about an equilibrium position without remaining in it. In this case it would be statically stable, but would have zero damping and hence, be dynamically unstable. With negative damping a projectile would oscillate with continually increasing amplitude following an initial perturbation even though it were statically stable. Equilibrium is obtained if the sum of the hydrodynamic, buoyant, and propulsive moments equal zero. In general, propulsive thrusts act through the center of gravity of the projectile so only the first two items are important.

If a projectile is rotating from its equilibrium position so as to increase its yaw angle positively, the moment coefficient must increase negatively (according to the sign convention adopted) in order that it be statically stable. Therefore, for projectiles without controls or with fixed control surfaces, a negative slope of the curve of moment coefficient vs yaw gives static stability and a positive slope gives instability. For a projectile without controls, static stability is necessary for a successful flight unless stability is obtained by spinning as in the case of rifle shells. For a projectile with controls, stabilizing moments can be obtained by adjusting the control surfaces, and the slope of the moment coefficient, as obtained with fixed rudder position, need not give static stability. Where buoyancy either acts at the center of gravity or can be neglected, equilibrium is obtained when the hydrodynamic moment coefficient equals zero. For symmetrical projectiles this occurs at zero yaw angle, i.e., when the projectile axis is parallel to the trajectory. For nonsymmetrical projectiles, such as a torpedo when the rudders are not neutral, the moment is not zero at zero yaw but vanishes at some definite angle of attack. Where buoyancy cannot be neglected equilibrium is obtained when $C_M = -C_{Buoyancy}$, and the axis of the projectile is at some angle with the trajectory.

For symmetrical projectiles the degree of stability, or instability can be obtained from the center-of-pressure curves. If the center of pressure falls behind the center of gravity, a restoring moment exists giving static stability. If the center of pressure falls ahead of the center of gravity, the moment is nonrestoring, and the projectile will be statically unstable. The degree of stability or instability is indicated approximately by the distance between the center of gravity and the center of pressure. In general, for nonsymmetrical projectiles, the cross force or lift is not zero when the moment vanishes so that the center of pressure curve is not symmetrical and the simple rules just stated cannot be used to determine whether or not the projectile will be stable. In such cases careful interpretation of the moment curves is a more satisfactory method of determining stability relationship.

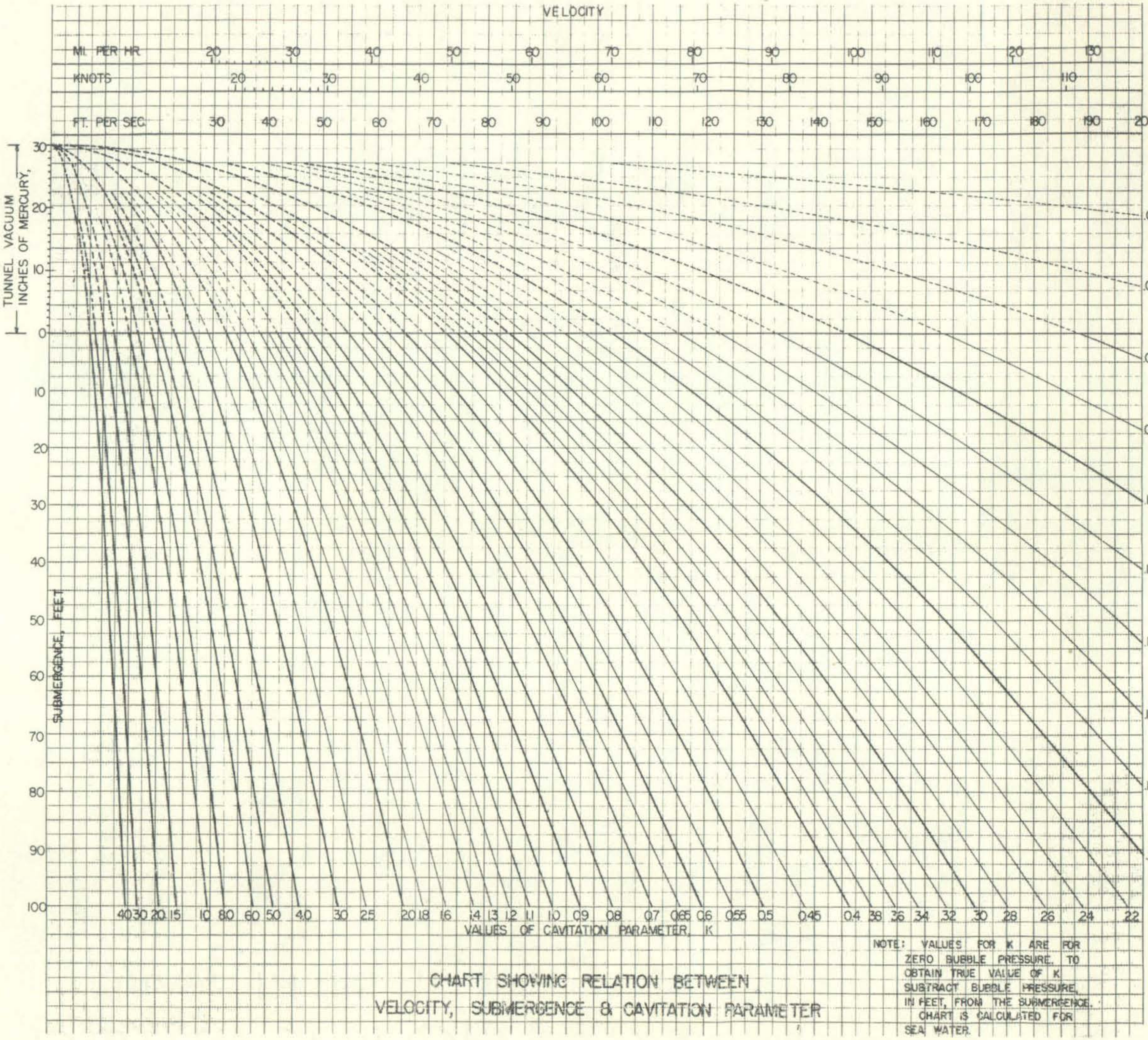


CHART SHOWING RELATION BETWEEN VELOCITY, SUBMERGENCE & CAVITATION PARAMETER

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